



Research



*National Centre for
Engineering in Agriculture*

Feasibility of Solar PV Irrigation in Queensland

REPORT 1: Solar Power and Solar Irrigation Systems

Prepared for Queensland Government (Department of Natural Resources, Mines and Energy)

Michael Scobie, Erik Schmidt, Les Bowtell,
Andrew Hill and Angel Garmendia



Table of Contents

Executive Summary.....	3
1. Introduction and Scope.....	5
2. Methodology	7
3. Solar Power and Solar Irrigation Systems	8
3.1 Energy Management and Renewable Energy	8
3.2 Benefits of Renewable Energy Technology	10
3.3 Solar Energy in Agriculture	10
3.4 Solar Radiation	11
3.5 Solar Irrigation Systems	14
3.6 Solar Irrigation Configurations	15
3.7 Solar Panels	19
3.8 System Controller and Inverter	23
3.9 Water Storage Options.....	24
3.10 Solar System Feasibility and Sizing	24
3.11 Diesel vs Electric Pumping	25
3.12 Pumps and Electric Motors	26
3.13 Variable Speed Drives	27
4. Case Studies	30
5. Conclusions	32
6. References	33

Executive Summary

This document is the first report in a series of three publications which discuss the feasibility of solar PV powered irrigation systems in Queensland.

These reports provide a useful resource to inform the feasibility of solar PV powered irrigation in Queensland by:

- Identifying and discussing the technology of solar power and pumping systems.
- Outlining incentive and funding opportunities for solar pumping systems.
- Reviewing Queensland agribusinesses' irrigation systems, efficiencies and crop and irrigation water requirements.

These reports do not provide a detailed address of grid connected solar PV rather focussing primarily on potential for standalone solar PV and diesel hybrid systems.

Solar irrigation must be considered in a holistic (whole of system) manner. Water demand should be seen as the critical starting point. Understanding irrigation demand is as important as understanding the technologies involved in the conversion of solar energy to electricity, to meet this demand.

When considering solar irrigation the starting point is an analysis of current energy usage. This is followed by an evaluation of energy conservation and efficiency opportunities of the current system, before finally looking at appropriate renewable energy technologies.

This report provides a technical summary of solar power and solar irrigation systems in Queensland.

Queensland is geographically large, spanning a wide range of latitudes and climatic zones. Solar radiation varies with latitude and has seasonal and daily variations, which Queensland farmers must consider. This variability in energy supply is important when designing a solar irrigation system to match variable crop irrigation requirement. In irrigation, hybrid systems are generally used, where solar is combined with power from the grid or a diesel generator to allow continuous power delivery for pumping.

Diesel pumping is common in Queensland cotton irrigation, while electrical pumping is more common in the sugar, dairy and horticulture industries where there is generally better access to the electricity grid. Diesel systems are generally more expensive to operate and maintain than electric systems and electrical pumping offers benefits of easier integration with solar, lower running costs and less maintenance.

Solar pumping systems are well suited to transfer operations in which pumps run during daylight hours to fill a storage. The size of the storage needs to be

determined on a case by case basis to balance the timing, duration and amount of high intensity irrigation, with the flow rate and operating period of the solar pump.

Farms that have relatively continuous and predictable day time irrigation needs are more appropriate for standalone solar irrigation systems. In most large scale irrigation systems (cotton, sugarcane, etc), irrigation and pumping requirements are highly variable and require more complex assessment.

Report 2 in the series introduces a number of incentives, funding opportunities and programs to support uptake of solar systems, including Small-scale Technology Certificates through the federal Renewable Energy Target, and Feed in Tariffs (for grid connected systems). There are also a range of energy efficiency loans, energy services agreements or project specific funding from agencies such as the Queensland Rural and Industry Development Authority. Businesses can apply for finance through the Clean Energy Finance Corporation and the banking sector with reduced rates and fees, due to the renewable nature of infrastructure.

Finally, **Report 3** outlines a number of factors that impact the scale of and potential market opportunities for solar irrigation systems in Queensland. These factors include:

- Crop water use and irrigation requirement for different industries.
- Typical capacity of irrigation pumps.
- Pumping costs and pumping efficiency.

1. Introduction and Scope

On 30 November 2016, the Queensland Government, as part of its response to the Queensland Productivity Commission's Electricity Pricing Inquiry Final Report, announced the Regional Business Customer Support Package (RBSCP). As part of this package, the Government made a commitment to investigate opportunities to utilise solar PV for water pumping and irrigation.

The Department of Natural Resources, Mines and Energy (DNRME) subsequently engaged the University of Southern Queensland to undertake research into the potential for solar PV as a replacement or complementary system for diesel powered irrigation and water pumping.

USQ were commissioned to summarise existing information on and initiatives around solar pumping relevant to Queensland. A review of Queensland agribusinesses' irrigation systems, efficiencies and crop and irrigation water requirements was also to be provided.

Prior to this engagement, much work has been undertaken by others on this topic. The Queensland Governments Energy Savers Plus Program, which has now been extended under the Affordable Energy Plan (Business Energy Savers Program), has produced a number of high quality case studies and reports. The NSW Government and NSW Farmers Association have also published excellent user friendly manuals on solar PV for irrigation and separately for stock watering. These have been a key resource for the technical components of this report. NSW AgInnovators provides good resources and explains the technology and components in a solar PV system.

By agreement with the Department of Natural Resources, Mines and Energy, this project does not provide substantial detail on grid connected solar PV and has been limited to standalone and diesel hybrid systems, including battery storage.

Solar irrigation must be considered in a holistic (whole of system) manner. Water demand should be seen as the critical starting point, rather than the solar hardware perspective. Understanding irrigation demand is as important as understanding the technologies involved in the generation (or more correctly the conversion) of solar energy to electricity.

Figure 1 illustrates the flow of energy and water through an irrigated agricultural system. Consideration of water demand from crops (irrigation) and stock watering and the water source (surface or groundwater) is the starting point. The technical requirements of the solar PV system in terms of pressures and flow rates are determined by this, which will impact the hardware (panels, battery, inverter, motor and pump).

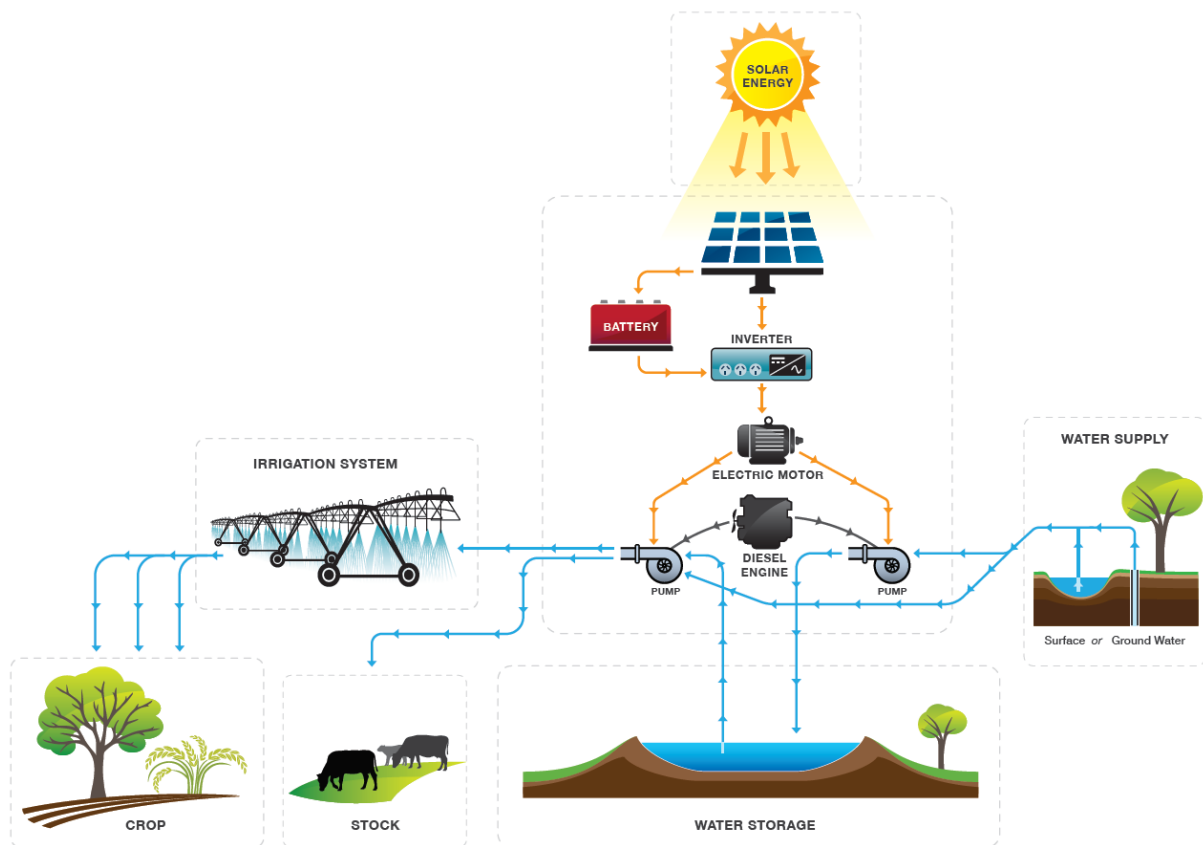


Figure 1 - Whole of system approach to solar PV water pumping

2. Methodology

The project methodology combined desktop assessment, and ground truthing through discussions with key stakeholders on both the supply and customer side of solar PV irrigation systems. This included:

1. Reviewing existing technical information on solar power and solar irrigation (this report)
2. Collating information on initiatives around solar pumping (Report 2)
3. Assessing Queensland agribusiness' pumping capacities, and irrigation and water requirements (Report 3)

For this technical report, information on solar power and solar irrigation systems from around Australia was reviewed and the range of configurations and standards for solar powered irrigation, as well as other key factors, was documented. This included a review of the benefits of renewable energy technology and the potential for solar energy in agriculture. Various solar irrigation configurations and components have been documented and factors influencing solar system feasibility and sizing have been outlined.

3. Solar Power and Solar Irrigation Systems

The sections below provide an overview of existing information around solar pumping with links to relevant information. Much of the material is based on excellent resources provided through the Queensland Government's Energy Savers Plus Program, NSW Government through its Office of Environment Heritage, NSW Farmers Association, well as NSW AgInnovators.

3.1 Energy Management and Renewable Energy

Renewable energy uptake varies across industry sectors. Centralised grid connected industries make up the highest proportion of renewable uptake. It is estimated that 40 percent of dairy farms have installed renewable energy; these include but are not limited to solar PV panels, heat-pumps or solar thermal (Clean Energy Finance Corporation, 2017).

With increasing electricity and fuel costs impacting farmers and industry, there is developing interest in renewables forming part of the on farm energy mix. Renewable technologies are increasing in efficiency with lower capital costs. These techniques, coupled with better access to finance and mechanisms such as power purchase agreements, are making renewables a more financially viable option.

When looking at renewables there has to be a clear plan of what each individual business requires and future plans for expansion. Figure 2 outlines the ideal model of how renewables can be introduced to the business, focusing first on analysis of current energy usage, then proceeding to evaluation of energy conservation and efficiency opportunities, before looking at appropriate renewable energy technologies. Renewable energy options should not be considered until all other energy management steps have been addressed.

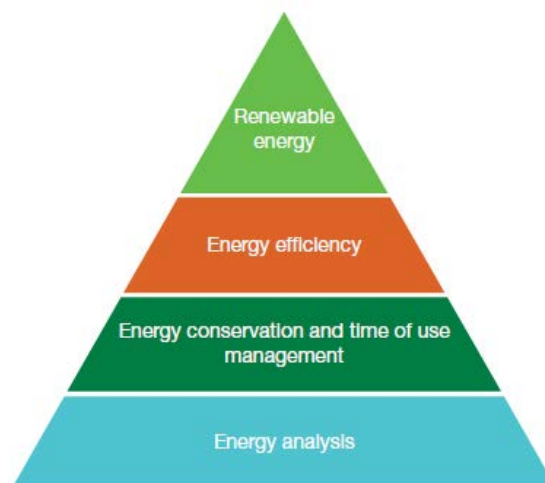


Figure 2 The energy management pyramid. (NSW Farmers, 2015b)

Energy analysis

Energy analysis can be done at different levels of detail, including:

- Level 1: a preliminary approach to assess aggregate energy use across all farming operations, to allow comparison against other enterprises.
- Level 2: to determine in greater detail energy use in specific farming operations and processes such as planting, harvesting and other tractor and pumping operations to identify high energy use operations on the farm.
- Level 3: a detailed measurement of duty cycle, load, and energy consumption for a specific operation such as irrigation pumping. This requires expert knowledge and detailed measurement.

Energy conservation and time of use management

Energy conservation and time of use considerations are important to assess impacts of different tariffs (day/night irrigation) and seasonal variation in energy demand. Time of use and pumping duration is informed by crop irrigation needs and infrastructure constraints.

Energy Efficiency

An important aspect of energy efficiency is ensuring the right amount of water is supplied to the crop at the right time. The pump must be suited to the job of matching supply with demand. Irrigating 12ML/ha when the crop needs 8ML/ha means that you are using 1/3 more energy than is necessary.

3.2 Benefits of Renewable Energy Technology

There are a range of benefits of renewable energy technologies, these are discussed by NSW Farmers (2015b) in a farmers guide to renewable energy technology and feasibility in agriculture and outlined below.

Supply security: By generating power locally the pump or load is less susceptible to blackouts, brownouts, voltage spikes or fuel (diesel) supply and one is able to move towards energy independence.

Flexibility: Ability to pump directly from renewables, use them to store energy or switch to diesel when required, using communication networks to update the owner with important information e.g. generator is out of fuel, pump information or electricity usage.

Savings: Renewables can reduce maintenance costs, fuel usage and time. Savings can also be made through efficient practices as part of an energy analysis before renewables are installed as part of a holistic plan.

Regional and community benefits: Often by reducing farm and business energy demands, electricity supplies in remote communities will stabilize and reduce the likelihood of blackouts and other associated electrical issues. There can be a reduction in community electricity grid/infrastructure upgrades which can be costly.

Green credentials and product differentiation: Environmental impacts are reduced which provides marketing opportunities by being able to promote “Sustainably grown” or “Green”, this can add value through customer perception.

Environmental benefits: Reducing dependency on fossil fuel reduces pollution at point of use and from the supply chain.

High Infrastructure Costs and Accessibility: Renewables can be used where installation of new power lines would not be cost effective, with the additional benefit of being able to be placed almost anywhere. Reduce the need to install new infrastructure in remote communities due to no additional load.

3.3 Solar Energy in Agriculture

Application of solar in agriculture can vary depending on the requirements of the farm or business. Several options are listed below as mentioned in NSW Farmers (2015b).

- **Processing:** Typically installed on a building, where access to the grid and roof top space is available and often installed on processing, packing or storage sheds for heating, cooling, lighting or processing. This type of installation primarily is used to reduce electricity bills, if the system is of sufficient size it can provide an additional source of income or offset additional equipment energy requirements.

- **Stock Watering:** Where water is pumped from a river or bore in small quantities for stock water requirements, typically systems are small in size (<2kW) and located in isolated areas.
- **Diesel/Solar hybrid pumping:** Either part of a new system or supplementing an existing diesel generator where solar panels can reduce fuel and maintenance costs, while also providing additional energy that can be used to store water or irrigate crops.
- **Direct Irrigation:** Farmers and business with high seasonal demand can use solar systems to augment or supplement existing grid or diesel systems and can be placed in remote areas. Solar systems are scalable, reliable with low maintenance.

This report focuses on the use of solar for irrigation and will discuss typical solar irrigation system components and how they contribute to efficiency within the whole installation.

3.4 Solar Radiation

The key requirement of a solar irrigation system is solar radiation, which is subject to seasonal and daily variations. Typically there is only 7-8 hours during the day that can provide significant energy, with mornings and afternoons considered shoulder periods producing lower levels of energy. Summer has higher solar radiation levels than winter and seasonal variations can cause changes to PV power output of 25% (Figure 3). Solar radiation availability will also vary for sites with different latitudes and different climates (e.g. a region highly prone to overcast or rainy days will have a lower solar radiation resource)(NSW Farmers, 2015b).

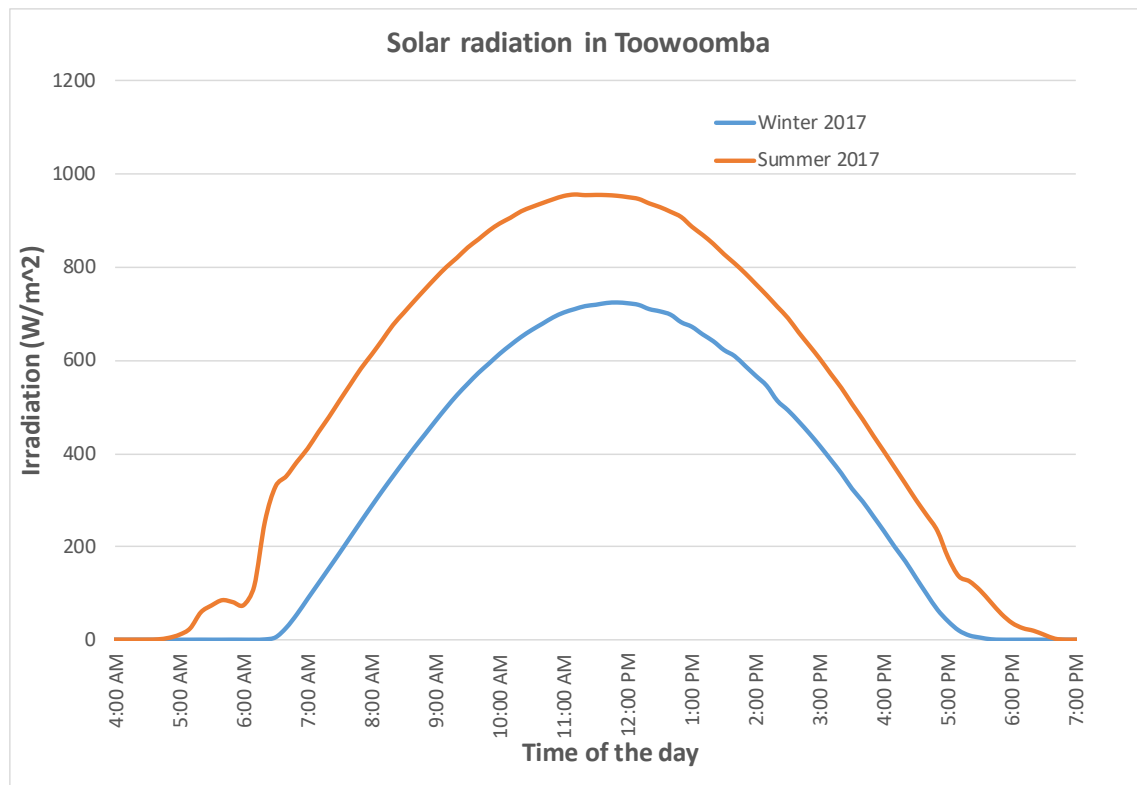


Figure 3 Difference in solar radiation levels across the day between summer and winter in Toowoomba

Figure 4 and Figure 5 depict typical Queensland solar radiation exposure for winter and summer months. These figures show that in the irrigation regions in Queensland there is reasonably high solar radiation and therefore substantial potential for solar PV irrigation. The size of the system will need to be designed for local conditions, to ensure that reliability of supply can be met. There is more variability in the summer months due to Queensland's summer dominant rainfall and therefore cloud cover during this period.

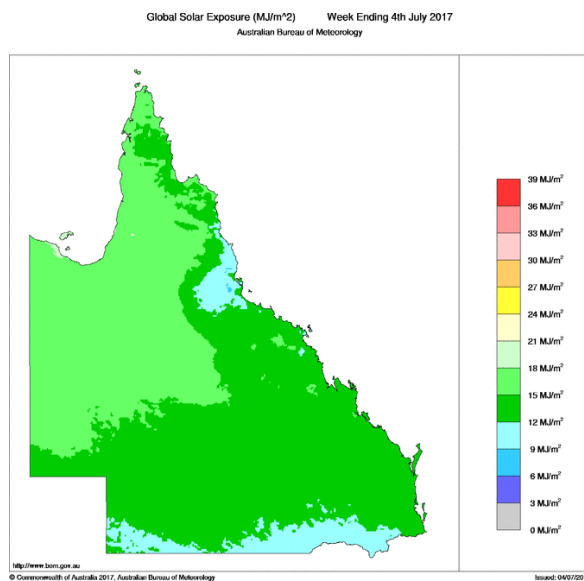


Figure 4 QLD Solar radiation map (Winter)
(Australian Bureau of Meteorology, 2017).

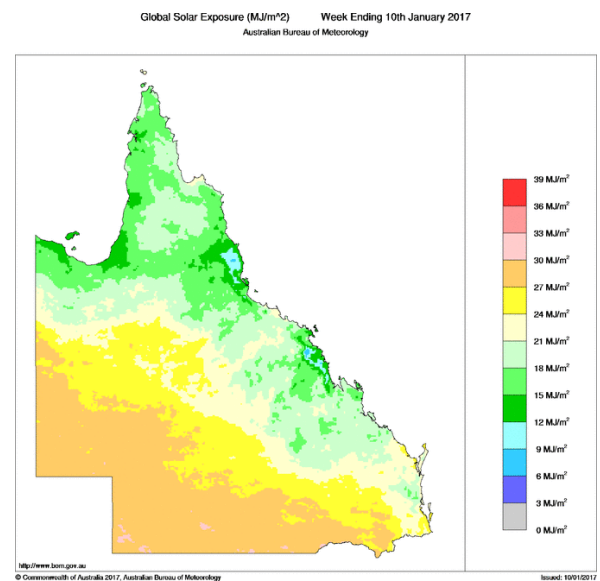


Figure 5 QLD Solar radiation map (Summer)
(Australian Bureau of Meteorology, 2017)

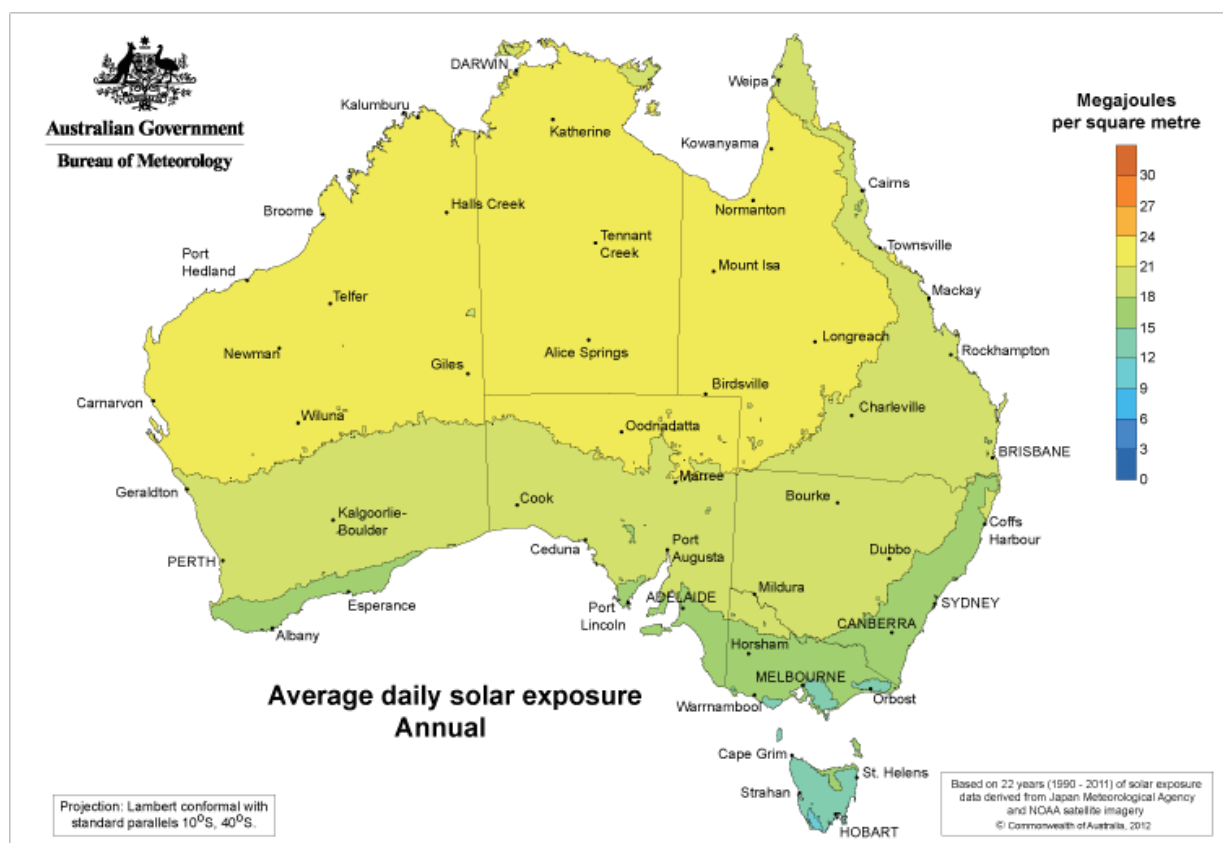


Figure 6 Average daily solar exposure Annual (Australian Bureau of Meteorology, 2017).

Figure 6 shows the daily annual Australian sun exposure showing the range of solar radiation across the other states and territories

3.5 Solar Irrigation Systems

NSW Farmers Association and NSW Office of Environment and Heritage have developed a useful manual on system selection and design for solar powered pumping in agriculture. Key aspects are identified below.

Energy coming from the sun can be converted into electricity using solar photovoltaic panels. Figure 7 shows a typical solar pumping system and the components used.

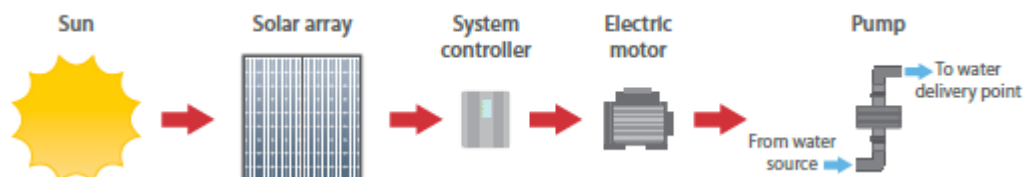


Figure 7 Solar pumping components (NSW Farmers, 2015c).

NSW Farmers Federation (2015c) outline key elements of a solar pumping system :

- **Solar radiation.** The amount of energy received from the sun at a given location. This determines how much power each solar module will generate in a day and the size of array needed to pump a required volume of water. A site with low solar radiation levels, such as the northern coastal areas of Queensland, with summer radiation of around 15MJ/m^2 , will need a larger array than a site in central Queensland with high solar radiation levels of 30MJ/m^2 .
- **Solar array.** A generator that converts solar radiation into electricity. An array consists of solar modules (panels), a mounting structure and electrical safety equipment.
- **Control systems.** The units that control the array and the pump. The array control system optimises the production of electricity from solar energy by means of an inverter/regulator and matches the electricity to the pump's motor requirements. The pumping control system controls when and for how long the pump operates.
- **Pump and motor.** The pump moves the water from a source to its delivery point. It needs to be powerful enough to move the necessary volume of water the required distance in the time available.
- **Battery storage and other generators.** Backup electricity can be provided by batteries that store excess solar energy or by additional generators, such as wind turbines or diesel generators.

3.6 Solar Irrigation Configurations

The following sections discuss typical photovoltaic/solar panel system configurations and how the energy is used for pumping.

Solar Alone

The solar panels provide power in the form of Direct Current (DC) due to radiation from the sun. The DC power is then provided to a motor by a system controller which regulates the panel(s) and motor, thereby controlling the pump output (Figure 8). This type of system is typically used to provide a constant water supply or for storage in a trough or dam and is ideally suited to stock and domestic installations. This system is often relatively low cost, small and independent of other systems, therefore is suited to use in remote areas (NSW Farmers, 2015c).

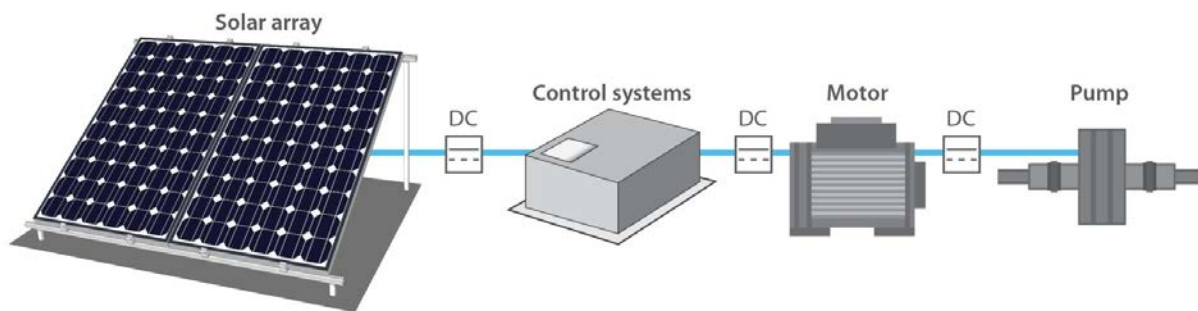


Figure 8 Solar pumping configuration, using just solar as the energy source (NSW Farmers, 2015c).

Solar combined with batteries

Figure 9 shows the addition of batteries as a storage device. The batteries are used to provide power to the pump when the solar panels cannot (e.g. low light, night time or cloudy weather). The battery bank can be sized to suit almost any type of application. Most batteries for this type of application are costly and size will depend on pump/load requirements. The batteries may require additional cooling/infrastructure due to temperature limitations. This makes a battery backup system more suited to small loads (<1kW) that require continuous operation (24 hours) or on-demand systems (NSW Farmers, 2015c).

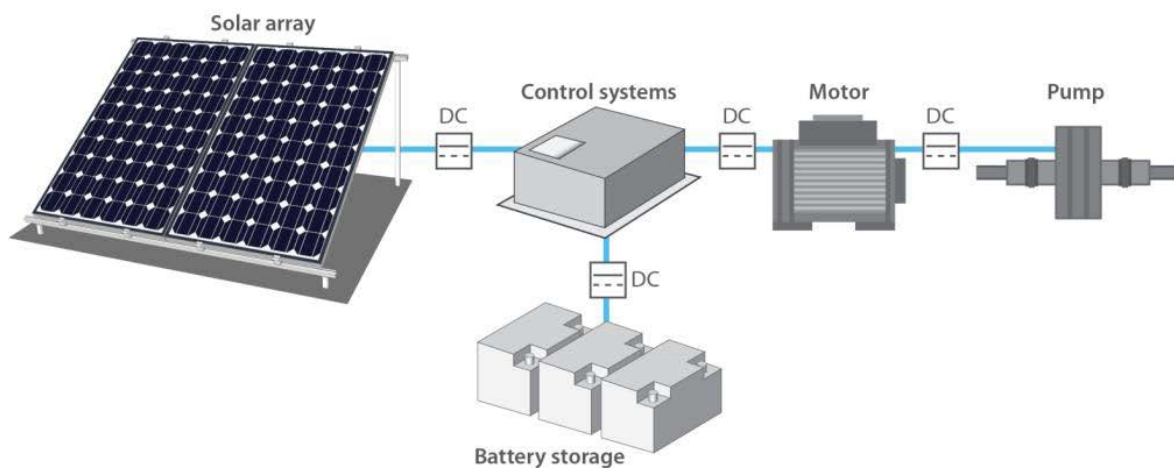


Figure 9. A solar pumping configuration that uses a combination of solar and batteries as the energy source. (NSW Farmers, 2015c).

Solar combined with diesel generation

With the addition of a diesel generator the system is capable of delivering power continuously. When the panels cannot provide sufficient power for pumping the diesel generator will be started. Hybrid systems are essential when solar is being used for large scale irrigation. The generator outputs Alternating Current (AC) where the solar panels output DC. Thus an Inverter has to be fitted to the system. The inverter allows AC to pass through and converts the solar array DC to AC. The motor/pump components would have to therefore be AC devices as shown in Figure 10. This system would be used for high loads that need to run continuously, for example direct irrigation rather than water storage. This system also shows how current diesel pumping systems could be adapted to take advantage of solar (NSW Farmers, 2015c).

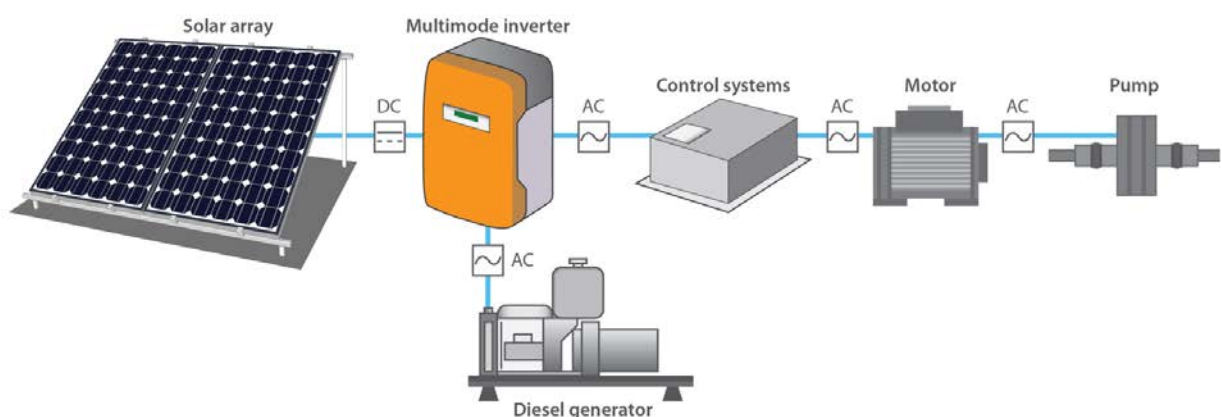


Figure 10 Solar pumping configuration that uses a combination of solar and diesel as the energy source (NSW Farmers, 2015c).

Solar combined with power from the electricity grid

The combination of solar with grid connection is similar to the solar/diesel system with the added advantage of being able to supply any unused power generated from the solar panels back into the grid for a rebate (Figure 11).

The solar array will generate power when sunlight is available and can be used to supplement or completely supply the irrigation pump. When the solar panels are unable to generate power, the inverter will source power from the grid. The excess power sent to the grid from the solar panels can effectively be utilised by other business processes or equipment connected to the grid.

This system has advantages over the solar/diesel hybrid as it provides the lowest maintenance, better reliability and utilises electricity rebates to offset costs.

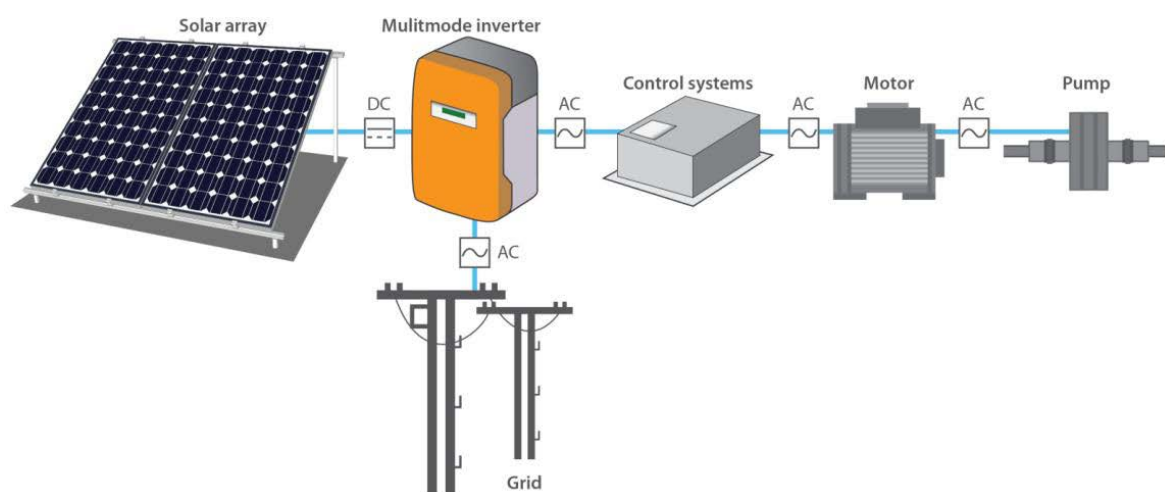


Figure 11 Solar pumping configuration, using a combination of solar and grid power as the energy source (NSW Farmers, 2015c).

Figure 12 shows how a solar grid connected system can be scaled according to requirements, costs and the proportion of power that could be exported to the grid. Payback periods vary depending on how the system is sized (NSW Farmers, 2015c).

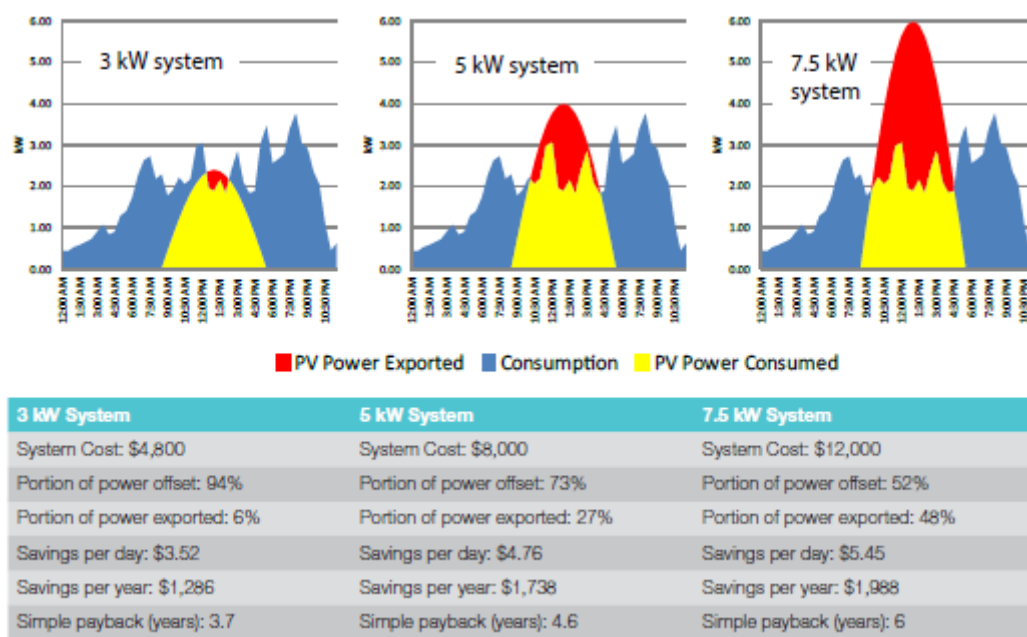


Figure 12. An example comparing three grid connected solutions and the expected generated power that will be consumed, the generated power that will be exported and the simple payback rates of each system (NSW Farmers, 2015b).

Floating Solar

The efficiency of solar arrays are dependent on temperature (among other parameters), the cooler the array, the higher the efficiency or output. This, combined with spatial constraints of large arrays, has led to the development and use of floating solar arrays. By floating the solar array over an open water body there are gains in panel efficiency, a reduction in evaporation water loss and increased land availability, when compared to land mounted systems. Floating systems can be implemented on almost any water body such as irrigation dams, reservoirs or rivers.

The floating solar array consists of a raft or platform on which solar panels are mounted. The electrical components are mounted on land, with the DC power generated from the array transported via cable to the main switch board on land. Variations on this design can include concentrator panels and solar tracking to improve efficiency.

Floating solar systems have been used to power water treatment systems for treating a variety of water quality issues (Infratech Industries, 2017). However maintenance on a floating array may be high.



Figure 13 Floating solar array (NSW Farmers, 2015b).

3.7 Solar Panels

Solar panels are a collection of smaller solar cells which are predominantly made using two different technologies: Crystalline Silicon and Amorphous or Thin Film Silicon. The predominant type in the marketplace are crystalline silicon panels as these are a more mature technology. In this type of panel, increased module temperature will reduce power output from the panel. There has been improvement to the efficiencies in Amorphous technology, which is gaining market position (NSW Farmers, 2015c).

The Crystalline Silicon technology can be separated into two different types' monocrystalline and polycrystalline.

Monocrystalline cells have the highest efficiency, but have higher production cost per watt. The cells are manufactured using molten silicon and are dark blue and uniform in colour (NSW Farmers, 2015c).



Figure 14 Monocrystalline Panel (NSW Farmers, 2015c)

Polycrystalline cells are slightly lower in efficiency than monocrystalline cells, but also have lower production costs. They are made from allowing molten silicon to cool which gives it the unique segmented look and are often lighter blue in colour (NSW Farmers, 2015c).

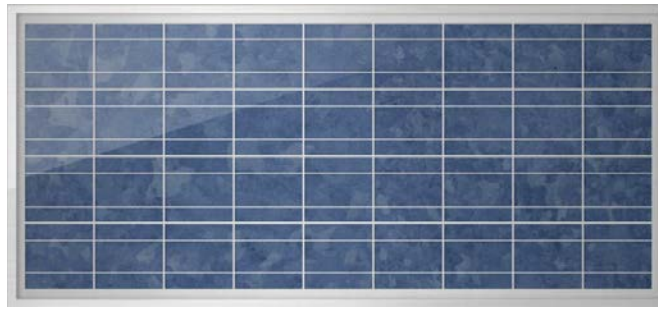


Figure 15 Polycrystalline Panel (NSW Farmers, 2015c)

The **Amorphous or thin film** technology provides comparatively low efficiency, but also costs the least to produce, and performs well in low light situations. The panels are also not as susceptible to high temperature effects.

The cell has a very dark blue almost black appearance and often no perceivable cell division lines. Due to the technology the solar cell can be printed on various materials most notable is flexible substrates, which allow the panel to be used in a variety of situations such as camping, uneven surfaces, material surfaces, etc (NSW Farmers, 2015c).



Figure 16 Amorphous Panel (NSW Farmers, 2015c).

Location (shade)

Shading of the solar array will reduce the systems output. The shading can vary throughout the day and season, therefore array placement has to be carefully considered. Solar service providers are able to provide advice on correct placement.

If an individual panel is partially shaded it can develop faulty cells, this will reduce the panel or array efficiency. Possible sources of shading include:

- Vegetation – trees, bushes, long grass, leaves
- Structures – buildings, shelters, fences, power poles
- Landforms – hills, rocks

- Array infrastructure – not leaving enough room between rows of tilted modules can cause one row to shade the row behind it.

Microinverters on the panels can also assist in reducing the impact of shading on part of the array but will incur an extra cost. There are professional shading analysis tools that allow accurate assessment of shading throughout the year. Examples of these tools include Solar Pathfinder and Solmetric Suneye (NSW Farmers, 2015c).

Orientation (tilt)

The orientation of each panel contributes to the efficiency of the whole system. A typical rule of thumb is each panel should be north facing (in the southern hemisphere) with the angle of tilt equal to the latitude on the installation location for best year round performance. This rule of thumb should be adjusted to suit the energy use profile and individual requirements. For example if a farmer requires the most power during summer months the panel tilt should be lower than latitude to take advantage of the higher sun orientation (NSW Farmers, 2015b).

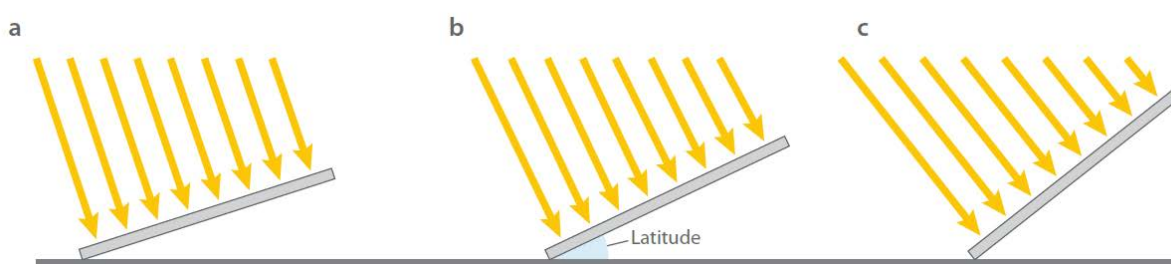


Figure 17: Optimal Panel Tilt a) A lower tilt – greater solar power generation in summer; b) A tilt equal to site's latitude – greatest annual solar-power generation; c) A steeper tilt – greater power generation in winter (NSW Farmers, 2015c).

Table 1 - Latitude and angle of tilt for optimum solar power generation in Queensland

Location	Latitude / angle of panel tilt
Dirranbandi	28.5°
Stanthorpe	28.6°
Darling Downs/Lockyer	27.6°
Bundaberg	24.9°
Emerald	23.5°
Mackay	21.1°
Bowen	20.0°
Burdekin	19.6°
Mareeba	17.0°

Depending on use, panels should be adjusted from latitude by -10° to -15° for best efficiency during summer months and conversely panels should be orientated +10°

to +15° during winter months for best performance. The panels can also be directed to either east or west depending on highest use times.

Solar Tracking

Tracking systems can control either the angle of tilt, and/or the direction, that the array (or individual panels) faces relative to the sun's position in the sky, using mechanical motors. This is achieved through either passive or active systems. Passive systems can be pre-programmed with sun data such as position and intensity, to follow the sun and requires no more information to operate. Active systems use the real time sun position to manoeuvre the panels or array into position, this type of system continually feeds data to mechanical components to orientate the panels for best performance.

Tracking systems can increase efficiency up to 10%, but can be expensive to construct and install, tracking is more suitable to large-scale arrays and areas with long sunlight hours. Alternatively a combination of both fixed and tracking system can be used, with the tracking component used to prolong the output of the system (NSW Farmers, 2015b).

The report Solar-Powered Pumping in Agriculture by NSW Farmers (2015c) outlines the two main forms of tracking systems:

- **Single-axis trackers** rotate the array in the east-west axis only, following the sun at a fixed angle of elevation from the time it rises in the east until it sets in the west. Installing a single-axis tracker solar PV array results in higher power output in the mornings and evenings.
- **Dual-axis trackers** rotate the array on an east-west axis and tilt it on a second axis so that it is angled directly towards the sun at all parts of the day.

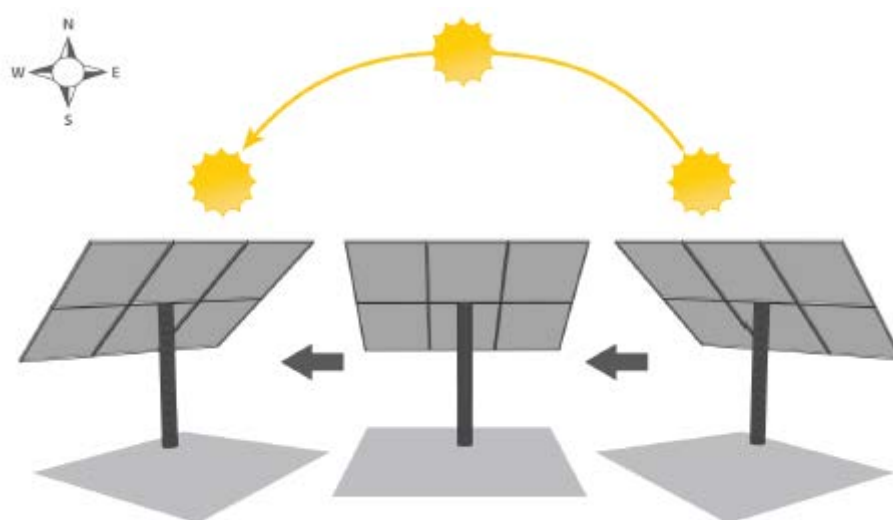


Figure 18. The single axis tracker follows the sun from east to west (NSW Farmers, 2015c).

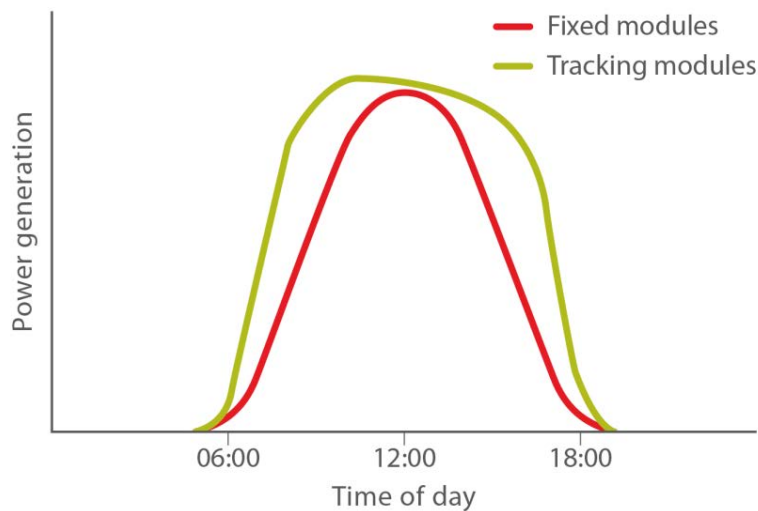


Figure 19 A single-axis tracker will result in higher power output from a solar PV array in the early mornings and evenings. Cooler morning temperatures mean that the array's morning output will be slightly higher than its evening output; a module's power output reduces as it heats up (NSW Farmers, 2015c).

3.8 System Controller and Inverter

Controller

Power generated by a solar panel is characterised by current and voltage. These parameters can be plotted on a Current-Voltage (I-V) curve. Depending on the operational conditions, the panel can operate anywhere along the curve. Electronic devices are used to manipulate the I-V to a given point on the curve.

There is a point along the I-V curve known as the 'knee' (Figure 20) that will produce the most power, this is called the maximum power point (MPP). This MPP does not always correspond to the correct voltage or current for the system or load. In these cases a maximum power point tracker (MPPT) is used to electronically control these variations electronically and produce the most power available (NSW Farmers, 2015c).

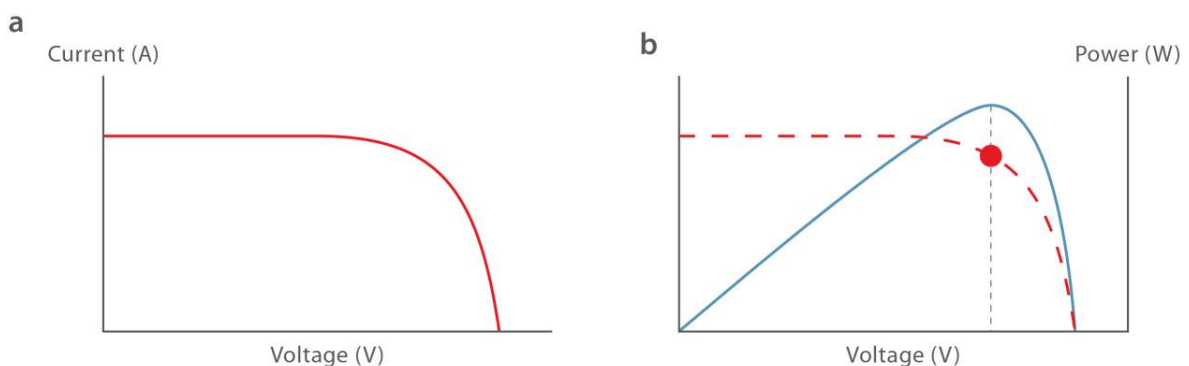


Figure 20: a) The I-V curve of a PV module (current is typically abbreviated as 'I' although its units of measure are Amps); b) the maximum power point of the I-V curve is at the red dot. Note: This point corresponds to the maximum point on the blue 'power output' curve (NSW Farmers, 2015c).

NSW Farmers Association (2015c) have indicated that without an MPPT, the PV array would need to be oversized so that it can provide the start-up current requirement of the motor. If the array has not been oversized to include some redundancy, in cloudy weather, the array may not operate at a high enough current to start the motor, even though it would have enough current/power to run the motor once it has started.

Inverter

Inverters make up approximately 20% of a typical solar system cost and are used to convert the array Direct Current to more useable Alternating Current. There are two main types of inverters; transformer type, and transformer-less type. As the name suggest the transformer type incorporates a transformer; a wire coil wrapped around a laminate iron core. These tend to be heavier and cost less to produce. The transformer less type is a relatively new technology where semiconductors (electronics) are used to convert the electricity. Transformer less inverters are lighter, more efficient and react quicker to changes in power (Solar Quotes, 2018).

3.9 Water Storage Options

Solar pumping systems are well suited to transfer operations in which pumps run during daylight hours to fill a storage, then the water is used when required from the storage. Since capital costs of solar systems are high, but the energy source is free, it makes sense to install systems that are as small as possible, but run whenever there is sunshine.

The size or capacity of the storage needs to balance timing, duration and flow rate required for high intensity irrigation with solar pump flow rate and duration.

This system is effectively using the water storage as a battery. Where chemical batteries hold energy in the form of electricity, a water storage holds the energy as a volume of water stored at an elevation above the water source.

3.10 Solar System Feasibility and Sizing

When assessing the feasibility of a solar irrigation system, consideration needs to be given to the amount and timing of pumping, the volume and reliability of the water source, water storage capacity, and integration into the infield irrigation system. Consideration should also be given to integrating solar with other power sources. NSW Farmers Association (2015d) have provided useful guidelines on the feasibility and sizing of solar systems.

Farms that have relatively continuous and predictable daytime irrigation needs are ideal candidates for solar systems that fully replace mains power. As a result, many horticultural growers have already adopted solar in packing sheds. However, in most broadacre irrigation systems, pumping requirements are

seasonal and vary in response to climate. These systems require more complex assessment and design.

Where pumping is irregular or not always in day light hours, return on investment and optimal system size needs careful consideration.

Other factors include electricity demand on farm, ability to export and sell unused electricity and ability to offset night time mains electricity cost with savings on day time usage.

Prior to committing to a major system it is recommended to follow the NSW Farmers (2015c) guidelines as follows, which are applicable in Queensland.

- Commission a general energy assessment of your farm. This should include accurate documentation of the quantity, cost and timing of energy used by your irrigation system.
- Address energy efficiency savings first. Poor layouts, pipe diameters, incorrect pump size and maintenance are all typical energy wastage points.
- Check the capacity of your water storage infrastructure and minimise leakage and evaporation.
- Involve your irrigation engineer to clarify priorities and technical requirements (e.g. Total Dynamic Head, pressure, control systems).

The sizing of a solar pumping irrigation system needs to take account of a range of factors. Guidelines on sizing solar pump systems and water storage have been developed by NSW Farmers Association (NSW Farmers, 2013a).

3.11 Diesel vs Electric Pumping

Diesel pumping is common in Queensland irrigation, especially in the cotton industry where the pump stations are often remotely located. Electrical pumping is more common in the sugar, dairy, and horticulture industries where there is generally better access to the electricity grid. Diesel pumping systems are generally more expensive to operate (refer Report 3: Queensland Agribusiness Pumping Capacities, Irrigation and Water Requirement) and maintain than electric pumping systems.

NSW farmers Association have a useful information sheet comparing diesel versus electric pumps (2015a). They indicated that in 2014 prices ranged between \$400 to \$500 per MWh for diesel pumping compared to electric pumping which can cost from \$150 to \$250 MWh (when grid connections are available). Electrical pumping offers benefits to installation such as ease of integration, quieter operation, lower running costs, less pollution and less maintenance.

Examples of the method to calculate payback on converting from diesel to electric pumping have been provided in the NSW Farmers (NSW Farmers, 2015a)

information sheet but will be highly variable dependant on the existing and proposed usage of the system. Cropping systems that require year round irrigation will have a shorter payback than short duration irrigated crops.

3.12 Pumps and Electric Motors

Solar pumping systems are typically sold as a package specifically designed to work with solar arrays in a complete system. Smaller pumps are often used for these continuous low flow operations e.g. stock watering, dam replenishment, nurseries, etc. These pumps often operate off a DC motor without the need for inverters or complex control systems.

In larger irrigation systems both AC motors and DC motors are suitable.

- The DC motor is limited by voltage, current and design of the motor. Control of the DC motor is achieved through two main methods, series resistance; which is very inefficient and Pulse width modulation (PWM); which controls the winding current by inducing a frequency. With these methods the DC motor can easily have the shaft speed ramped up or down depending on requirements, it also reduces high initial start-up currents.
- The AC motor is controlled by the current frequency and number of poles which limits the synchronous speed of the motor. The difference between synchronous speed and actual rotational speed is known as 'slip'. The slip induces eddy currents which limit the motors current due to back electromotive force (EMF). A problem arises on start-up of the AC motor because there is no back EMF to limit current, therefore the initial currents in the motor can be much higher (up to 7 times) than the rated (running) current; this configuration is known as Direct On Line (DOL). The higher current only last for several seconds but if the design of the system is not capable of delivering the current it is possible the motor will not start at all (Global Sustainable Energy Solutions, 2015).

The AC motor would therefore not be suitable or efficient to be used with a solar array, without use of a soft start or Variable Speed Drive (VSD) to minimise initial start-up voltage.

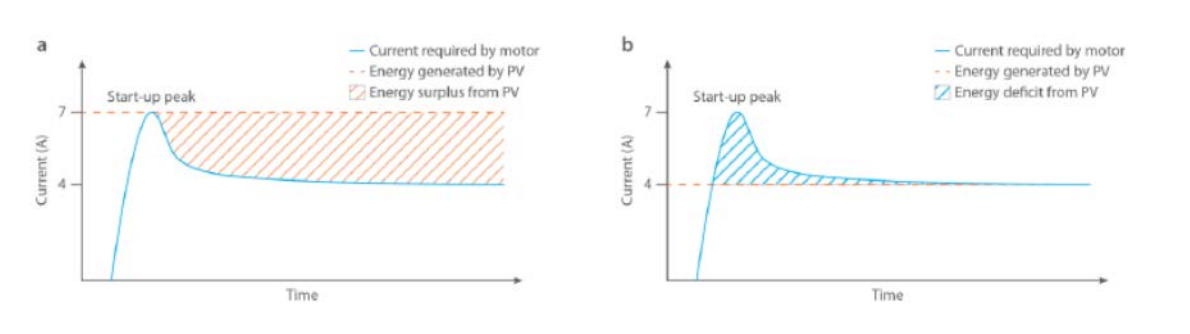


Figure 21: Motor surge current in DOL configuration would either prevent a PV array from starting the motor or result in an oversized PV array being installed (Global Sustainable Energy Solutions, 2015).

3.13 Variable Speed Drives

A variable speed drive (VSD) regulates the speed and rotational force (torque) of an electric motor. It controls the output of the motor by varying frequency and voltage. VSD's are becoming a standard inclusion as part of the solar water pumping system controller. The cost of a VSD is dependent on the size of the unit.

VSDs are often recommended for areas with relatively weak electrical networks, or remote PV supply, in order to minimise starting transient effects. In many pumping and irrigation systems, capacity controls are required and VSDs can perform this role well, although there may be simpler approaches (i.e. soft starters) that may work equally well.

VSDs allow a pump system to be tailored for a specific situation and optimised for a range of system constraints, they are however not always the best nor the only approach that should be considered as they have additional service and capital costs.

Global Sustainable Energy Systems (<https://www.gses.com.au>) have produced a range of technical papers on solar pumping systems including VSDs.

Hybrid capacity control of one or two of the pumps (as shown in Figure 22) with VSD or flow control valves allows the system to run continuously following the irrigation demand, reducing the need to start and stop and with minimal storage required. When the non-VSD pumps are run they can be started with soft starters and by-pass contactors for minimal starting impact and best operational efficiency once up to speed. The VSD controlled pumps allow flow control with lower losses than flow control valves and less cost than having all VSD system pumps.

This hybrid grid/solar system allows full control but significantly reduces demand in peak periods or low solar availability. They may also be further hybridised by including an auxiliary diesel generator to allow the system full autonomy on cloudy days or when the mains fails.

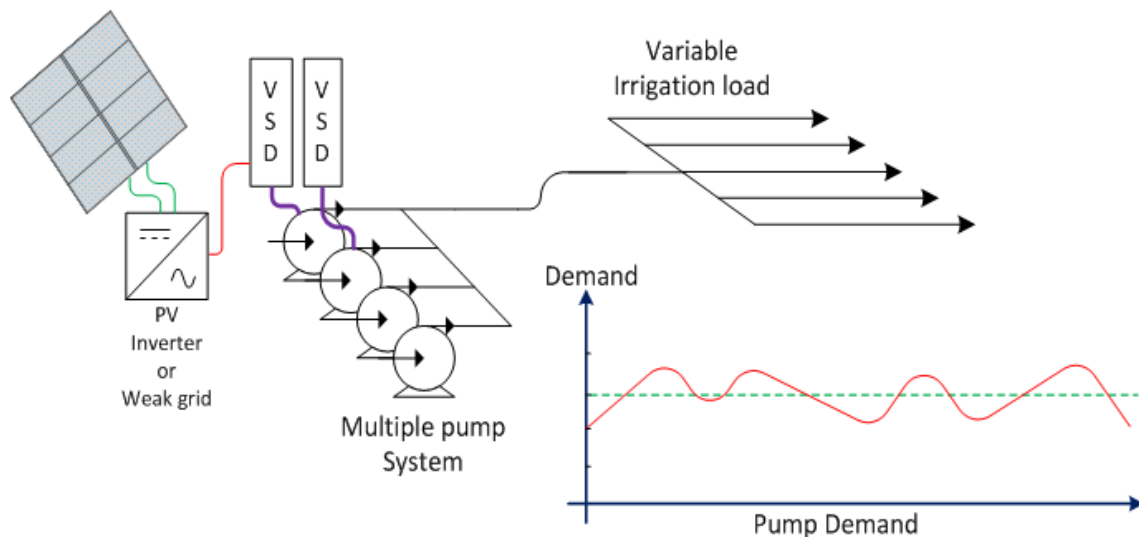


Figure 22 Hybrid capacity control with VSD

Current electronic systems and VSDs allow power to be drawn from either the solar PV panels or simultaneously from the PV panels and grid or diesel generators (solar assisted operation).

These systems draw energy from the PV panels to pump water, and if the output energy of the PV array is not enough, the system switches on the AC input from the generator or grid to “top up” and deliver all energy required by the motor. This feature is especially important when the AC is supplied by a generator and minimises diesel usage.

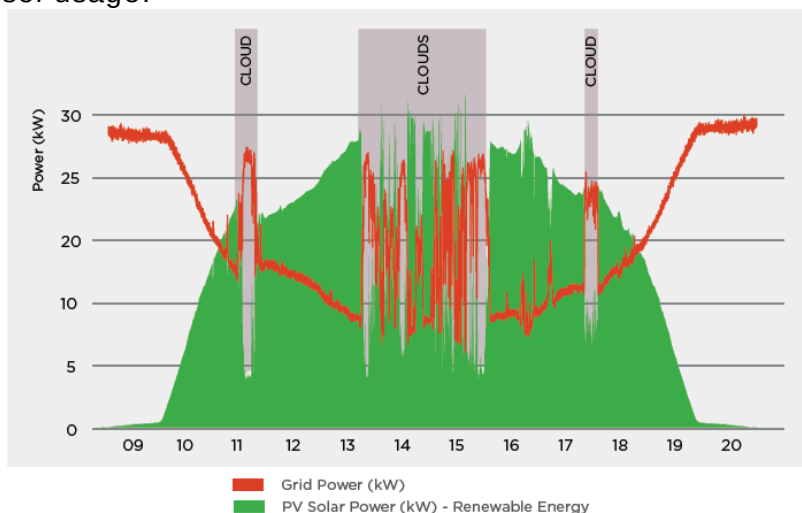


Figure 23: Switching power from solar PV to grid or diesel power in response to incident solar radiation (Example – Power Electronics SP 7000SP brochure).

The VSD will reduce operating costs by allowing the pump to run efficiently at varying loads, reduce maintenance cost due to less wear on pump/motor and reduce operational costs such as refuelling and monitoring. If a VSD is considered when installing a new system it can reduce the size of the required

solar array, inverter and/or batteries thus making further savings. NSW Farmers provide some key factors when evaluating quotes (NSW Farmers, 2013b).

4. Case Studies

There are a large number of interesting and informative case studies that demonstrate the use of Solar PV for irrigation. Links to some of these are included below.

1. QFF have published a number of case studies as part of the Energy Savers program which aims to assist farmers reduce energy costs by supporting the accelerated adoption of improvements in on-farm energy use. The Program is funded by the Queensland Department of Natural Resources, Mines and Energy, and The Department of Agriculture and Fisheries and implemented by Ergon Energy in partnership with Queensland Farmers' Federation
<https://www.qff.org.au/newsroom/case-studies/>
2. NSW Farmers the peak industry representative body for agriculture in New South Wales, have published a range of case studies in their AgInnovators web portal including ten on solar power systems for irrigation.
<http://www.aginnovators.org.au/case-studies/>
3. The company ReAqua have a large portfolio of successful solar PV installations covered in case studies
<http://www.reakua.com.au/case-studies/>
4. The company GEM Energy have included a case study on solar irrigation for horticulture.
<https://www.gemenergy.com.au/case-studies/>
5. The company Solar Pumping Solutions has published some case studies including a 100kW solar array powering a 55kW submersible pump at Narromine NSW
<https://www.solarpumping.com.au/projects/hybrid-solar-pumps-large-scale-irrigation>
6. The company Grundfos primarily serves the stock watering solar market and a case study is included below.
<http://au.grundfos.com/cases/find-case/Grundfos-providing-reliable-water-supply-to-mid-north-cattlestud.html>
7. The company YellowDot Energy has provided a case study on Australia's largest solar high-flow bore in Hillston NSW
<https://www.ydot.com.au/engineering>

8. NSW farmers have published a number of case studies as part of their farm energy innovation program, including some solar irrigation studies.
<http://www.nswfarmers.org.au/r-And-d-projects/reports-and-publications/case-studies>
9. Cotton Australia have published a number of grid connected solar irrigation case studies
<http://www.cottoninfo.com.au/publications/grid-connected-solar-irrigation-case-studies>

5. Conclusions

Solar pumping for stock watering provides a fairly standard technical solution, using low power pumps, with multiple suppliers and cost effective solutions. These are low risk solutions, where water demand can be readily met with supply.

Irrigation with solar PV poses significant challenges, given system size and the need to match pumping capacity with variable crop water demand. Irrigators generally need high reliability in water supply. Solar irrigation does not provide this, unless there is a large and cost effective battery storage, grid connection, or diesel hybrid system.

Solar irrigation must be considered in a holistic (whole of system) manner. Water demand should be seen as the critical starting point. Understanding irrigation demand is as important as understanding the technologies involved in the conversion of solar energy to electricity, to meet this demand.

Hybrid solar PV irrigation systems typically have high capital outlay but low operating costs. They are best suited to irrigation throughout the year from an assured water supply or for continuous pumping to storage.

It is important to recognise that the first step in considering renewables is an energy analysis or audit of the pump station, to assess the existing efficiency of the diesel pump and motor, which provides a baseline from which gains can be measured. The broader issues of how the pump system is integrated into farm irrigation practice, to meet varying seasonal crop water requirement are critical.

In grid connected systems, a key problem is the network connection cost and electricity tariffs. Solar systems linked to the grid have become attractive, however reduced feed in tariffs are making this less economical.

When considering solar PV for water pumping consideration needs to be given to other renewables and broader regional solutions. There needs to be continued broader research into renewable energy options for irrigation. These include use of bio-diesel and ethanol fuel blends manufactured from local products such as oil seed and sugarcane biomass.

There are significant opportunities for large institutions such as water supply authorities and electricity network providers to make use of solar technology to better manage their assets, especially as part of integrated smart grid solutions.

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